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Simulation for the Secondary Loop of the Chinese 200Mwe HTR-PM Base on Vpower

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Abstract

HTR-PM simulator is urgently developed as one of the important major sub-projects of the HTR-PM which is one of the Major national science and technology projects. The HTR full-scope simulator is currently still a blank throughout the world. In this situation, based on the vPower simulation platform, the structure of the simulation system of secondary loop was presented in detail in this paper, and the whole system was jointly debugged between secondary loop and the steam generator of Nuclear island side by embedding THERMIX /BLAST code into the vPower simulation environment. Steady state and transient process of some key parameters have been studied by the help of this simulation system. Current simulation results analysis shows that it is agreed with the design values and expectations and fitted for practical application

Keywords- Engineering simulator; High-temperature Gas-cooled Reactor; Modeling and Simulation; Secondary loop system

1. Introduction

The Pebble-bed Modular High Temperature Gas-cooled Reactor (HTR-PM) under construction in China has shown great potential as one of the next generation reactors for electric power generation due to its high thermal efficiency and inherent safety. It is very important that HTR-PM simulator is developed as one of the important major sub-projects of the HTR-PM which is one of the Major national science and technology projects. As one of the important major sub-projects of the HTR-PM， HTR-PM engineering simulator[1]can be applied for: (1) verification of system design and system integration, (2)

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power test simulation, (3) plant transient and accident analysis, (4) plant abnormal and emergency procedure development and verification, (5) design change verification and analysis, etc. But all the simulators developed are compact simulators, in which detailed models on reactor system equipment are established, while the secondary loop system are simplified so greatly that there are many limitations in analysis and it is not suitable for power plant operating personnel to conduct intensive training and assessment. Therefore, the establishment of a complete system model for the HTR-PM full-scope simulator development has great significance.

The vPower simulation platform[2], developed by Beijing Neoswise Technology Co., Ltd., is a simulation environment for power system with open architecture, fully object-oriented approach and friendly human interface. In this paper, the structure of the simulation system of secondary loop is presented in detail based on the vPower simulation platform, and the whole system is jointly debugged between secondary loop and the steam generator of Nuclear island side by embedding THERMIX /BLAST code[3]which is a thermal-hydraulic analysis code designed by German-Julich Nuclear Research Center for pebble-bed HTRs, into the vPower simulation environment.

2. Modeling of Secondary Loop System

According to the structure characteristics[4] of the secondary loop system of the HTR-PM, simulation modules are mainly developed with intrinsic models of vPower simulation platform other than some parameters regulating and program amending. These models include the Steam Turbine, condenser, deaerator, high and low pressure heaters, pumps, valves and piping etc. Modules Graphical automatic modeling method based on the modular modeling is used in vPower simulation system. In the graphical modeling environment, the module is represented with an intuitively graphical image or icon and is connected with directional line. In this way, the process of constructing user's system simulation model is to draw the module icons together first, and then to establish connections between them according to the actual system structure. (shown in Fig.1, Fig.2 and Fig.3)

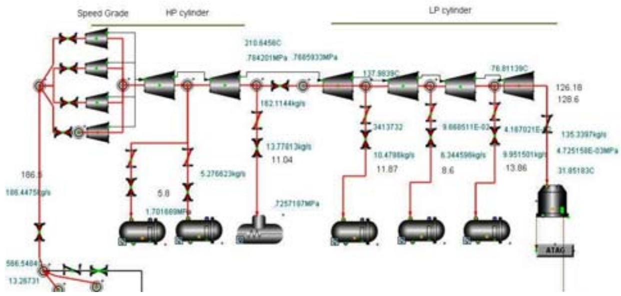

Figure 1. Main steam and steam extraction system

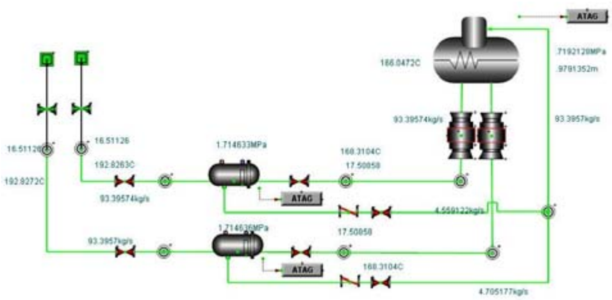

Figure 2. Feedwater system

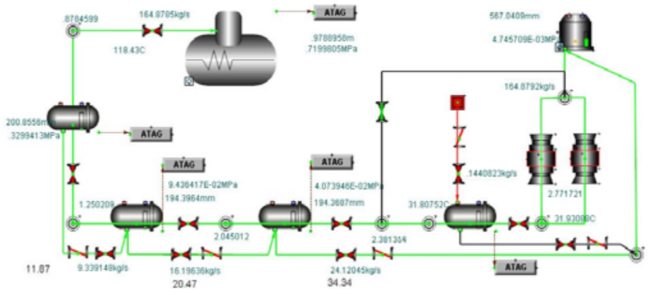

Figure 3. Condensate System

3. Modeling of the Htr-Pm Thermodynamic System

In the compact HTR-PM engineering simulator, two THERMIX modules are applied to simulate the operation mode of two pebble-bed module reactors coupled with one steam-turbine generator[5], both of which are synchronized on the vPower simulation platform. The simulation modules for the secondary loop, control system, safety & protection system and human machine interface are mainly developed with intrinsic models of the vPower simulation platform. The simulation scopes of the compact HTR-PM engineering simulator and the collaboration between the two THERMIX modules and the vPower simulation platform are shown in Fig.4

The compact HTR-PM engineering simulator is based on THERMIX/BLAST code, which is a mature analysis program of pebble-bed high temperature gas-cooled reactor and consists of thermal-hydraulic model, neutron kinetics model, loop model and steam generator model. Including the modeling of reactor system with THERMIX/BLAST, the connection of all components of HTR-PM is shown in Fig.5

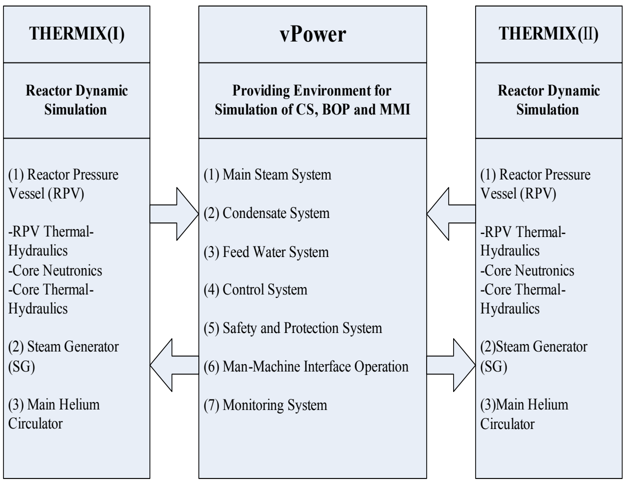

Figure 4. Collaboration between two THERMIX modules and vPower simulation platform

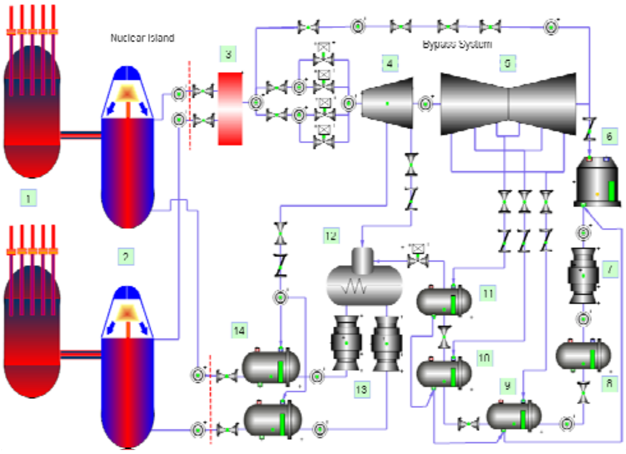

Figure 5. Modeling of HTR-PM thermodynamic system

4. Simulation Result and Analysis

4.1 Secondary Loop System Model Steady Calculation Results

Thermodynamic system model of the HTR-PM reactor system and secondary loop system is integrated and debugged to the steady-state. Comparing important simulation parameters with the HTR-PM design parameters of full-power, as shown in Table 1, it can be seen that the basic margin of error is within 2%, which illuminates that the reliability of secondary loop system model simulation is satisfactory.

TABLE I. ERROR ANALYSIS OF THE SECONDARY LOOP SYSTEM KEY PARAMETERS

Parameters	**Design**	**Simulation**	**Error (%)**
Turbine Power(MW)	211.5	210.8	0.33
Main steam flow(kg/s)	186.5	186.3	0.11
Main steam pressure (MPa)	13.24	13.21	0.23
High-pressure cylinder steam flow (kg/s)	186.04	186.3	0.14
Low-pressure cylinder steam flow(kg/s)	162.85	161.5	0.83
Low-pressure cylinder inlet pressure(MPa)	0.77	0.765	0.65
Condenser pressure(KPa)	4.5	4.48	0.44
Deaerator pressure(MPa)	0.7472	0.7418	0.72
Feedwater flow(kg/s)	186.5	186.3	0.11
Feedwater pressure(MPa)	16.4	16.43	0.18
Feedwater temperature (℃)	203.8	202.2	0.79

4.2 Analysis of Transient State

The compact HTR-PM engineering simulator can also be applied to simulate transient and accident states. One reactor is running on steady state (100% of rated power) with the operation parameter, and the other reactor is running in an accident condition caused by the loss of helium mass flow[6]. The dynamics of main parameters are very important for transient state analysis, such as Main steam pressure, steam temperature, steam mass flow, feedwater temperature and mass flow, etc., and the curves make us more intuitive to observe the trends of key indicator.

Two examples of the process of the Second Circuit transient response are following：

a) Valve adjustment made a small down-step at 100% FP condition. Main steam flow decreased rapidly, while the pressure increased rapidly after the stable. Turbine power decreased rapidly and remained stable after short-term oscillations. A set of data were drawn every 0.5s into the dynamic curves in Figure 6, Figure 7 and Figure 8. They showed the phenomenon of the failure of the simulation and the actual phenomenon of fault line.

b) Feed water made a small down-step of 20%. The transient simulation of the two reactors can be observed as a small down-step of feed water of one reactor may influence the other reactor and the thermal parameters of the system(Figure 9).

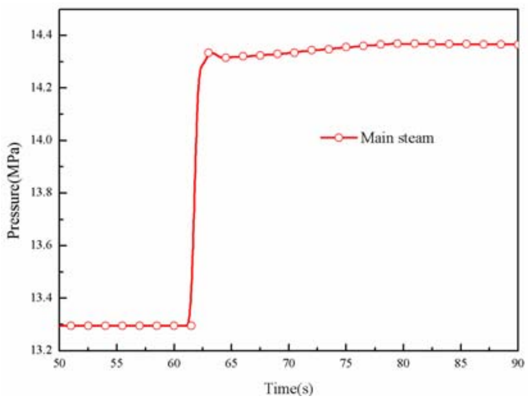

Figure 6. Main steam pressure

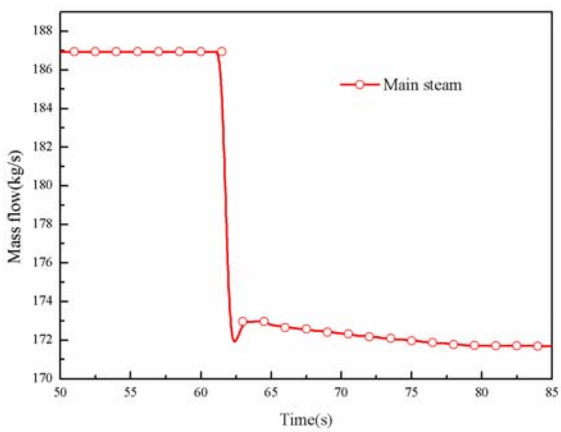

Figure 7. Main steam flux

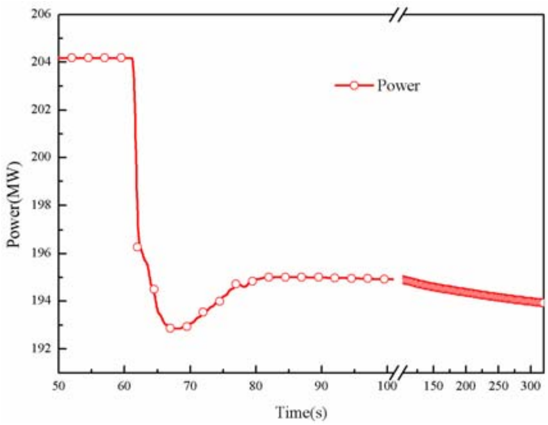

Figure 8. Turbine Power

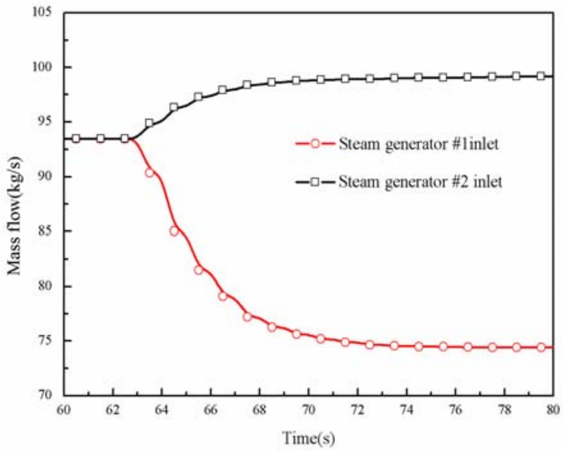

Figure 9. SG#1 and SG#2 Feedwater flux

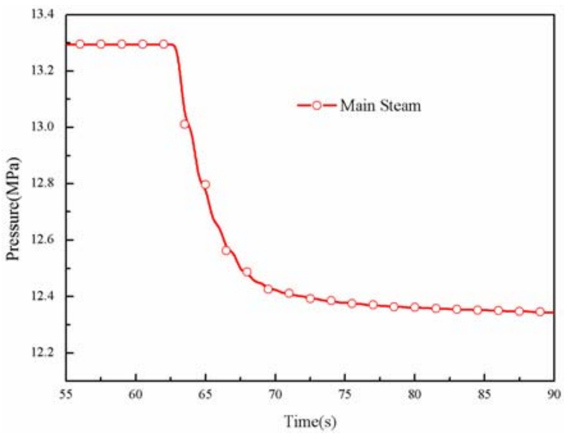

Figure 10. Main steam pressure

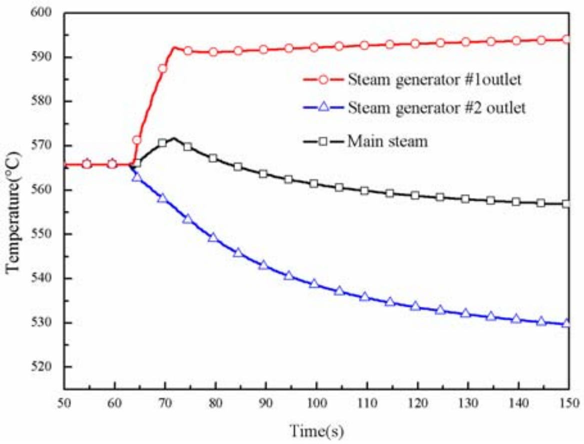

Figure 11. SG#1 and SG#2outlet and Main steam temperature

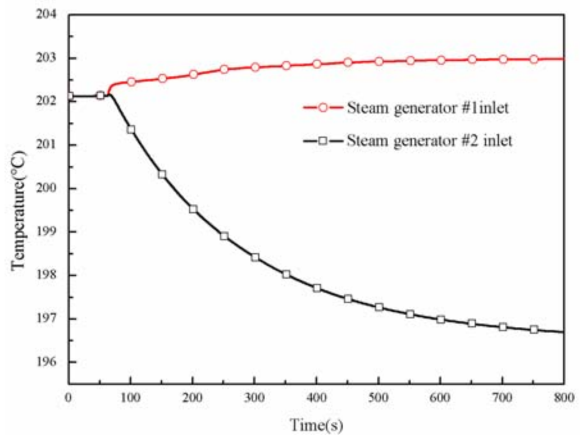

Figure 12. SG#1 and SG#2 Feedwater temperature

5. Conclusions

The compact HTR-PM engineering simulator by embedding THERMIX/BLAST code into vPower simulation platform is applied to simulate the behavior of the HTR-PM under steady state, transient and accident conditions. Current simulation results analysis shows that it is agreed with the design values and Expectations and fitted for Practical application.The compact HTR-PM engineering simulator will be improved and validated for performing safe analysis, procedure development, and design change verification of the HTR-PM in the future.

Acknowledgment

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